CALSPAN CORPORATION

STABILITY, CONTROL AND FLYING QUALITIES DEMONSTRATION TO PILOTS OF NASA LANGLEY RESEARCH CENTER

FLIGHT I SYLLABUS

JUNE 1976

SYNOPSIS

The primary purpose of this first flight in the variable stability B-26 is to illustrate typical airplane stability and control characteristics and their relationship to airplane flying qualities. In particular, the longitudinal characteristics are shown beginning with a demonstration of various static stability levels. The longitudinal dynamic modes are identified for the statically stable airplane. Discussed in more detail next are those factors which are dominant in the maneuvering characteristics of the airplane: short period dynamics, maneuvering force levels, and stick travel. The effects of control system friction and centering springs are also demonstrated. Lateral-directional characteristics are shown but only in a general sense to identify them and establish their relevance to flying qualities.

A brief pilot evaluation of a particular longitudinal configuration is used to illustrate proper flying qualities evaluation techniques. In particular, the generation of meaningful pilot comments and the use of the Cooper-harper rating scale are emphasized.

A. INTRODUCTORY COMMENTS

1. Prior to Takeoff

- Evaluation pilot station and its pertinent features.
- Cockpit procedures including bailout.
- Aircraft maneuvering envelope.

2. After System Engagement

- Open-loop or free response of an aircraft as opposed to closed-loop or pilot-in-the-loop response.
- Test inputs; common errors; effect of control friction on input.
- Qualitative assessment of response to pilot inputs and method of talking about it.

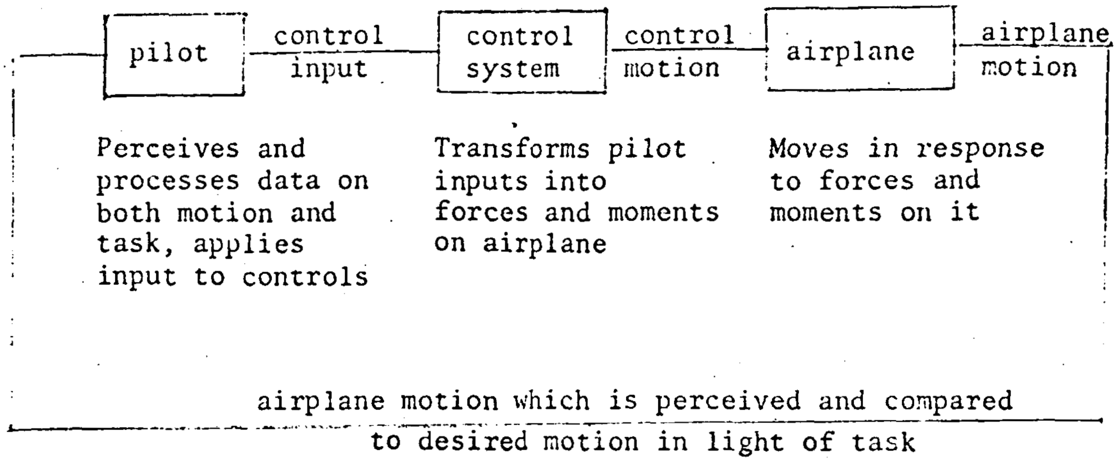
(NASA-TM-103455) STABILITY, CONTROL AND FLYING QUALITIES DEMONSTRATION TO PILOTS OF NASA LANGLEY RESEARCH CENTER. FLIGHT 1 SYLLABUS (NASA) 13 p

N90-70661

Unclas
00/05 0293165

B. LONGITUDINAL STATIC STABILITY

OBJECTIVE: To demonstrate effects on flying qualities of varying levels of static longitudinal stability of an aircraft and to introduce the relationship between static stability and corresponding dynamic characteristics. When a pilot flies an aircraft closed-loop, he generally relates aircraft response to his control inputs. Thus, he sees the lumped effects of basic airplane characteristics and control system characteristics.



Initially, the effects of varying basic airplane characteristics are shown with essentially constant control system characteristics. Then, with constant airplane characteristics, the very significant effects of the control system on closed-loop control are demonstrated.

1. Statically Stable Airplane (Positive Static Stability; C.G. ahead of static neutral point)

   - Demonstration pertains primarily to the situation with fixed-wing aircraft where static stability is derived predominantly from angle of attack stability (subsonic).

   - Discussion applies generally to airplanes with irreversible control systems and without bobweights.

   - Longitudinal free response motion consists generally of two second order dynamic modes:

(a) Short-term response or Short-period

- motion primarily in angle of attack, pitch attitude and "g"; airspeed and altitude essentially constant.

- mode through which pilot maneuvers airplane in pitch (Short period dynamics are discussed in more detail in Section C).

(b) Long-term response or Phugoid

- motion primarily in airspeed, altitude and pitch attitude with angle of attack essentially constant.

- the pilot usually notes the effect of the phugoid during trimming or in cruise flight rather than during maneuvering.

- Trim exists; for specific trim setting, there is specific corresponding pitch attitude and airspeed.

- Stick Force/airspeed gradient = $F_s/\Delta V$ is positive, i.e. pull force for speed below trim, etc.

- Steady-state stick force/normal acceleration = F_s/g is positive.

2. Neutrally Stable Airplane (Neutral Static Stability; C.G. at the static neutral point)

- Trim control commands pitch rate not pitch attitude.
- No speed stability $\rightarrow F_{ES}/V = 0 \rightarrow$ no phugoid.
- No angle of attack stability
- Have "g" stability $\rightarrow F_{ES}/g > 0$ due primarily to pitch damping (M_q).
- Elevator actuated either through the stick or the trim controls pitch rate. Aircraft short term pitch response is a first order mode in pitch rate akin to the roll mode - pitch damping (M_q) determines time constant and hence predictability in pitch attitude control much as τ_R affects bank angle control.
- Pitch damping and gearing are important factors in flying qualities of neutrally stable aircraft.
- With appropriate pitch damping and gearing, neutrally stable airplane can be readily flown in tasks where speed control is not critical - in fact for air-to-ground task, no need to retrim in dive as speed increases.
- In turbulence, airplane will heave but will not rotate in pitch.

3. <u>Statically Unstable Airplane</u> (Negative Static Stability; C.G. <u>behind</u> static neutral point)

- Exponential divergence in angle of attack; pitches slowly at first, then more and more rapidly. (<u>Unlike steady pitch rate of out-of-trim with neutral static stability.</u>)

- Negative stick force/airspeed change.

  (a) C.G. between static neutral point and maneuver point.

  - Stick force/g still positive; pitch damping stronger than angle of attack instability.

  - Flyable but requires pilot attention.

  (b) C.G. at maneuver point.

  - Stick force/g is zero for small region about balance airspeed (speed where sum of forces and moments are zero); stick force to <u>initiate</u> motion (overcome inertia) still in normal direction.

  - Flyable but sensitive; very easy to overcontrol.

  - Stick force/airspeed change more negative than Case (a).

  (c) C.G. behind maneuver point.

  - Stick force/g actually negative for small region about balance airspeed.

  - Flyable but requires constant attention.

  - Stick force/airspeed change still more negative.

C. INFLUENCE OF SHORT-PERIOD DYNAMICS

- Short period is of primary concern to the pilot for maneuvering tasks.

1. <u>Effect of Changing DAMPING of Short Period Motion</u>

- With medium frequency $\simeq$ .5 cps; 40 lb/g

Damping Ratio		Remarks
High	.7	Looks dead beat. Note time to settle down. Steady for tracking, easy to maneuver, but not particularly quick.
Low	.2	Overshoot easily noticed, interferes with quick maneuvers. Supersonic, high altitude, with pitch damper off.
Zero	.0	Not usable, although flyable. With friction, becomes almost unflyable.

2. <u>Effect of Changing FREQUENCY of Short Period Motion</u>

- With high damping ratio $\simeq$ .7; 40 lb/g

Frequency or Quickness of Response		Remarks
Medium	.5 cps	Typical of medium-sized airplane. Good.
Fast	.8	Quicker to get moving, quicker to settle down. More like fighter or small plane. Good for maneuvering, easy to get desired g. If forces are lighter, tendency to bobble or waver on target.
Slow	.3	More like transport. Stable, good for IFR, not good as fighter. Heavy forces okay for transport. Can force slow response to become faster by exerting high initial force.

NOTE: C.G. moving aft towards neutral point has the effect of reducing angle of attack stability (and hence speed stability) resulting in a weaker restoring moment in angle of attack and a lower frequency of the short period mode. In a similar fashion, moving the c.g. forward increases the short period frequency.

D. INFLUENCE OF ELEVATOR GEARING (F_s/g)

- With medium frequency ≃ .5 cps; high damping ratio ≃ .7

Stick Force/g		Remarks
Medium	40 lb/g	Suitable for this airplane. Adequate g-protection. No good if higher g maneuvers are required.
Light	20	Pilot maneuvers more quickly. Appears like higher frequency of short period. Really, open loop response unchanged but closed loop response quicker. Pleasant to maneuver. Remember from demo of effect of frequency, forces too light make pilot bobble with high frequency, overshoot with low frequency.
Heavy	85	Acts like transport. Pilot maneuvers slower. Looks like lower frequency of short period because heavy forces prevent pilot from applying enough elevator to get quick response. Notice heavy forces not bad if task does not require quick maneuvers and, in fact, prevent inadvertent quick maneuvers.

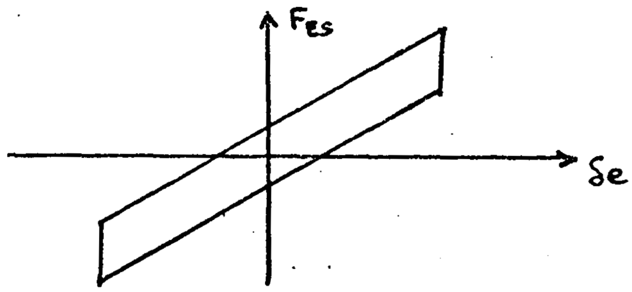
E. INFLUENCE OF STICK TRAVEL (Stick Feel Gradient)

- Shown with constant (open-loop) airplane characteristics, constant F_s/g.
- Zero stick travel/force input produces a faster responding airplane.
- Large stick travel/force input produces a slower or more sluggishly responding airplane.

F. LONGITUDINAL CONTROL SYSTEM NONLINEARITIES

OBJECTIVE: To demonstrate the interactions between elevator control system and the open-loop airplane characteristics during closed-loop (pilot-in-the-loop) task performance. The pilot essentially sees the two sets of characteristics as one integral lump.

1. <u>Friction or Force Hysteresis</u>



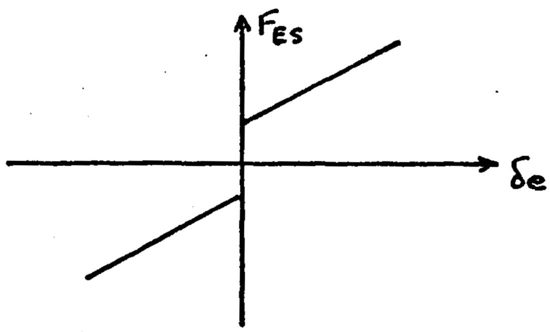
- Introduced with medium frequency (0.5 hz) well damped ($\zeta_{sp} \sim 0.7$) short period and $F_{ES}/g \sim 40$ lbs/g - note trimmability (impaired), ability to make small corrections (impaired), larger maneuvers (OK).

- With medium frequency (0.5 hz), zero damping, 40 lbs/g - note ability to track in pitch (worse than without friction).

- With high frequency (0.8 hz), moderate to well damped ($\zeta_{sp} \sim 0.4 - 0.7$), light $F_{ES}/g \sim 10$ lbs/g - note effect of small amount of friction on air to ground tracking (beneficial, less bobbling on target); too much friction detrimental.

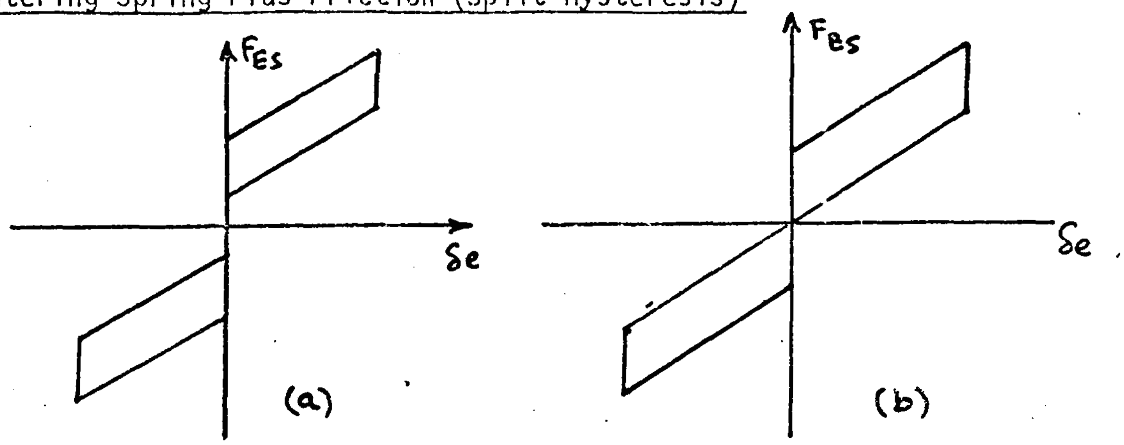
- With low frequency (0.3 hz), well damped ($\zeta_{sp} \sim 0.7$) and $F_{ES}/g \sim 20$ lbs/g - note effect of friction on pitch attitude control (detrimental because adds lag to an already slow initial response).

2. <u>Centering Spring</u>



- Shown with baseline configuration of $f_{sp} \sim 0.5$ hz, $\zeta_{sp} \sim 0.7$, $F_{as}/g \sim 40$ lbs/g - effects on small corrections in pitch and on pitch maneuvers similar to friction; due to positive centering, trimmability is positive.

3. <u>Centering Spring Plus Friction (Split Hysteresis)</u>



- Shown again with baseline configuration
- Gross effects similar to friction except for trimmability which is definite and predictable.
- Prefer minimum level of nonlinearity about the trim i.e. sketch (b)
- Centering spring is added to a system which has friction to improve trimmability.
- Breakout force is the sum of the friction and centering spring.

GENERAL COMMENTS:

Any control system nonlinearity tends in general to reduce airplane response predictability to stick force inputs. The particular nonlinearities demonstrated here introduce lags in the overall response to stick inputs. With many airplane dynamic configurations, this is detrimental. However, with some, particularly "sensitive", or "overly responsive", configurations, this lag can be beneficial.

H. PRACTICE EVALUATION

- Practice evaluation of longitudinal configuration
- Review of evaluation procedure, pilot comments and use of rating scale
- Emphasis of difference between flying qualities evaluation and documentation (collection of required flight test data).

CALSPAN CORPORATION

STABILITY, CONTROL AND FLYING QUALITIES DEMONSTRATION
TO PILOTS OF NASA LANGLEY RESEARCH CENTER

FLIGHT II SYLLABUS

LATERAL-DIRECTIONAL STABILITY AND CONTROL CHARACTERISTICS

A. DUTCH ROLL MODE

GENERAL CHARACTER: Combined rolling and yawing motion, coupled together. Period about 2-10 sec., damping light. Amount of rolling motion compared to yawing motion depends on aerodynamics and inertia of airplane. Can vary from mostly yaw to mostly roll.

Sideslip (β) makes airplane turn to line up with relative wind, as a weathercock (N_β). Once turning, inertia makes it continue to turn and therefore overshoot. Damping, due mostly to motion of vertical tail through the air as the airplane moves in yaw (N_r), makes the motion die out.

But, at the same time, the β produces roll due to the dihedral effect (L_β). Also, as airplane yaws, one wing moves ahead faster than the other, and so develops more lift and so makes airplane roll (L_r). As airplane rolls, angle of attack at down-going wing becomes greater, and smaller on up-going wing. Lift is perpendicular to on-coming air, so lift vector tilted, producing forward component on one wing, aft on other. This produces yawing moment (N_p). This increase in angle of attack on the downgoing makes more lift on the downgoing wing and hence a moment proportional to roll rate, or damping in roll (L_p), which provides part of the damping of the Dutch roll as well as affecting the roll mode time constant. In addition, the sideslip produces a lateral force on the airplane (Y_β).

All these effects interact, and couple the rolling and yawing motion together.

OBJECT: To identify the variety of aircraft open-loop (free response) motions that are due to Dutch Roll mode characteristics as described by its damping ratio, period (or frequency) and its roll-to-yaw ratio and relate these characteristics to the ability of the pilot to perform various closed-loop tasks in smooth and turbulent air.

1. Effects OF DAMPING RATIO: (With period and roll to yaw ratio kept constant.)

   0.1 Baseline. Many cycles to damp (watch turn needle). Consider damping needed in Dutch roll compared to longitudinal short period. Note oscillation while tracking, after using aileron to stop maneuver. Pilot can add damping closed-loop.

0 Unacceptable for normal use even though pilot can damp motion. Note roll-to-yaw ratio by watching wingtip-roll appears as vertical motion, yaw as horizontal motion of tip.

0.3 Typical with yaw damper. Note improvement in tracking, stopping on heading.

2. Effects of PERIOD: (Frequency) (With damping ratio and roll to yaw ratio kept constant)

4 Sec. Baseline.

2 Sec. Noticeable change. Like T-38. Perhaps not much practical difference in suitability. What do you think?

3. Effects of ROLL-TO-YAW RATIO: (With damping ratio and period kept constant)

1.2 Baseline: moderate dihedral effect.

0.5 Low dihedral effect. Flat, snaking motion. Like Bonanza Noticeable change but perhaps not much practical difference. What do you think? Rudder more help than aileron to damp motion; aileron works on roll (smaller part of motion), pilot judges results by seeing yaw (large part of motion).

5 High dihedral effect. Undesirable. Rolls too much for small yaw correction or rough air. Practical improvement by adding damping (and MILSPEC requires this). Damping by use of rudder not very easy. Rudder works on yaw (small part of motion), pilot judges results by seeing roll (large part of motion). Also, rudder generates sideslip which makes more roll due to high dihedral.

CONCLUSION: Open loop characteristics a convenient way to describe a set of airplane characteristics but importance is strong effect on the way the airplane responds in specific closed-loop piloting tasks.

B. <u>Effects of YAW DUE TO LATERAL CONTROLS - A Control System Characteristic</u>

OBJECT: Shows how airplane <u>open loop characteristics</u> (here-dihedral effect and hence roll-to-yaw ratio) determine the way that <u>control system characteristics</u> (here we are changing yaw due to lateral inputs affects the <u>closed loop control</u>, i.e., how well the pilot can make the airplane do what he wants it to.

1. Low dihedral (low roll-to-yaw ratio)

   a. Moderate Adverse Yaw - OK for small lateral control input, Dutch roll excited in quick maneuvers. Pilot can coordinate with rudder to suppress Dutch roll.

   b. Large Adverse Yaw - Like many light airplanes or STOL, some jets in PA. Rudder coordination now important.

   c. Proverse - Like spoilers. If too much, airplane starts yaw in turn too quickly, stops turning before wings reach level in recovery. Induces Dutch roll. Hard to coordinate.

All of the above are acceptable although different.

2. High dihederal (high roll-to-yaw ratio)

   a. Moderate Adverse Yaw - Not good but perhaps acceptable; rudder coordination now required. Note roll rate hesitation or reversal; aileron starts airplane rolling but adverse yaw produces sideslip. With high dihedral, get substantial rolling moment opposing roll due to aileron, so roll slows or reverses. Directional stability makes airplane turn to reduce sideslip. Then roll due to dihedral diminishes and airplane picks up roll rate again. Result - oscillatory Dutch roll superposed on desired roll rate and pilot objects. Use of lots of rudder helps start roll (L_β adds to L_{δ_a}) but also induces Dutch roll. Rudder - aileron interconnect now important, so pilot doesn't have to coordinate turn. Interconnect may operate only in PA, where low speed means high α , so high dihedral effect from swept wing, and high adverse yaw, because lots of aileron needed. Generates large β because vertical tail less effective at high α .

   b. More Adverse Yaw - Aileron not a good roll control. Aileron produces rolling moment but sideslip produced by adverse yaw is so large that roll due to dihedral cancels roll due to aileron. This approached in some delta wing airplanes. At low speeds roll control OK if rudder coordination good to keep sideslip small - reason for rudder-aileron interconnect.

c. Proverse - Now easy to start roll (sideslip induced by aileron produces roll which helps roll due to aileron). Note closed-loop oscillation. Pilot makes roll worse when he tries to stop roll. Typical of some swept wing transports in approach (C135). Controllable by pulse aileron input; roll mode time constant short compared to Dutch roll period so aileron pulse affects roll rate, but is removed before yaw due to aileron builds up sideslip to produce roll due to dihedral. Hard for pilot to coordinate rudder and cancel yaw due to aileron.

C. ROLL MODE: Effects of ROLL MODE TIME CONSTANT

OBJECT: To identify the roll mode which is the mode the pilot utilizes for roll control and demonstrate the effects of the roll mode time constant on the pilot's ability to control bank angle

- Shown with low dihedral (L_β) and small yaw due to aileron ($N_{\delta a}$) to minimize excitation of Dutch roll, which would obscure effect we want to show.
- A first order mode.
- τ_R is a function of roll damping and rolling moment of inertia.
- Note difference between how much steady state roll rate pilot gets for a given control input (a function of lateral control effectiveness and gearing) and how quickly pilot gets that steady state roll rate (a function roll inertia and roll damping).
- τ_R affects roll response predictability or one-to-one feel between aircraft response and pilot input.

1. Short (about 0.3 sec) - Time to reach steady very short. to pilot, aileron commands roll rate. Easy to stop precisely at desired bank angle.

2. Long (1.3 sec) - Time to reach steady p long enough to notice. Appears as slight pause while airplane picks up roll rate. Pilot tends to overshoot bank angle. With heavier ailerons, pilot makes input slower, more nearly matched to airplane roll response, and there is less overshoot. This more like large airplane.

D. SPIRAL MODE

- A first order mode
- Generally with a long time constant
- Shows up primarily in open-loop tasks such as trimmed cruise flight rather than with maneuvering flight.

1. Moderately Divergent - Annoying in cruise flight aircraft tends to roll off either side of level flight - requires continuous pilot monitoring.

2. Moderately Convergent - Annoying when making steady banked turns - requires steady lateral control inputs to counteract tendency to return to level flight.

CONCLUSION: Prefer as near neutrally stable spiral as possible.

E. PRACTICE EVALUATION

A complete simulated airplane configuration including both longitudinal and lateral-directional characteristics will be set up and given to the evaluation pilot for a flying qualities evaluation in the context, of a designated task. The Calspan pilot will monitor the pilot comments and suggest changes where necessary. The evaluation pilot will be expected to summarize his comments at the end of the evaluation utilizing the sample comment card and assign an appropriate pilot rating using the Cooper-Harper scale. This evaluation will be separate from the documentation of the configuration. The evaluation pilot should clearly separate the process of evaluation (Is it suitable for the task?) from the completely separate job of determining open-loop airplane characteristics. (Does it comply with the specifications?) Here, we will be interested in the first of these questions, i.e. How well can you do the job? How much effort and concentration did it take to do it? Could you count on being able to do it perhaps in conjunction with other piloting tasks? Did you have to compensate for some deficiency of the airplane?, and so on.